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ABSTRACT

As the proceedings of a symposium held at the 1973 Annual Meeting of the National Association for Research in Science Teaching, theoretical and experimental results from research in the use of information theory to study human learning are presented in this volume to reflect the efforts made at the University of Pittsburgh over the past four years. The information memory model in connection with various research schools is expositorily discussed, including the causal mechanistic and behavioristic approaches. A combination of the psychological and "artificial intelligence" theories and a quantitatively defined structure of the experiment information are the main concerns of the model as developed at Pittsburgh. Normal human behaviors are considered to be Markovian when treated as a sequence of subjects' behaviors in learning tasks. Experimental studies of nine of twenty principles underlying the development of th m [illegible] are described in this volume, primarily on a nonparametric bas[illegible] [illegible]e of the topics covered are memory processes, information f[illegible] [illegible]ligence and achievement measurements, task processing s[illegible] mental maturation, perceptive modalities, concrete and [illegible] [illegible]perations, and learning and cognition in sorting tasks. Four contributed papers are included to summarize the treatment techniques used. (CC)

SYMPOSIUM

The Use of Information Theory to Study Human Learning

Project on the Information Memory Model
University of Pittsburgh

Presented at the 1973 Annual Meeting of the
National Association for Research in Science Teaching
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Foreword

The symposium on the use of Information Theory to Study Human Learning at the 1973 Annual Meeting of the National Association for Research in Science Teaching reflects the efforts of a group of researchers at the University of Pittsburgh over the past four years. The group of researchers include, in addition to the presentors, B. Biglan, J. Black, B. Dean, C. Empfield, H. Orndorf, Somchit Pongreunkait and David Speer. They provided us with data and treatments from experiments which are mentioned in the symposium. Our thanks are extended for their efforts.

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Overview.

These proceedings are of a Symposium presented at the 1973 Annual Meeting of the National Association for Research in Science Teaching (NARST) at Detroit, Michigan. The theme was The Use of Information Theory to Study Human Learning.

The proceedings describe the use of a memory model which quantifies the quality of human behaviors in learning experiences. It was developed from some theorems originated by C. S. Shannon (1) in 1948. Shannon and other information theorists developed 11 theorems and algorithms for describing the flow of information between sources and receivers of a communication channel. Another 17 theorems and algorithms were developed by G. Moser. These were derived to account for tasks, behaviors, and memory components in human learning. The 28 model elements are now used to describe how the human memory operates for processing information in the acts of learning or cognition. All but two of these elements were defined by Moser (2) in a paper presented at the 1972 Annual Meeting of NARST. The new elements are described on page 4 of the proceedings.

The basic concepts of the model are that cognitive behavior is Markovian (see page 4 for a definition) and that the human memory operates in a logarithmic fashion to receive, store, and output information. These concepts may seem to be a "long shot" but this Symposium presents evidence for the plausibility of the claims. Five years ago the senior author decided that still another attempt should be made to apply the Shannon Theory to the study of human behaviors. A decade earlier several psychologists, including Attneave (3) and Miller (4), tried to apply the theory in interpreting psychological studies. Little success was realized, with the exception of it probably enhancing G. A. Miller's development of the Chunking Principle (4). The decline of the movement was probably due to an incorrect interpretation of the use of the theorems and the incompleteness of the set of theorems for describing all the elements and processes of human behavior.

The schedule of the project on an information memory model (PIMM) was to conduct learning behavior experiments and apply theorems to describe the behaviors. A two-level system concurrently operated for PIMM. The model was applied to learning behaviors which had real world orientations. The real world is defined as those psychological, philosophical, and pedagogical realities of learning behavior. Experiment tasks were selected to evoke findings known to recognized researchers. This approach enabled an interpretation of the memory model on two levels. Early in the project, we relied more heavily on the first level which was to confirm the findings of real world knowledge of behaviors. Then the model components would be examined for relationships with the real world interpretations. It soon became apparent that quite often the logic of the model interpretations was more plausible than that of the real world in explaining cognitive behavior.

The second level of activity of PIMM was to derive new model components where behaviors were being incompletely described. This was an exacting and perplexing task. Each model element exists in a quantitative form. The mathematical factors demanded continuous reviews of previous experimental results for inconsistencies and gaps in describing behavior. Then the mathematical rationale of the model would be stulied to derive a theorem. The new theorem would be applied to the data for testing model component compatabilities and real world consistencies.

The PIMM had a major problem in monitoring the psychophysiological research reported on learning behavior and the nature of the memory and its functions. An example of this problem is the controversy about the short and long term memory stores. The problem truncated into the psychologists viewpoint (5,6), and those of brain researchers (7). The second consideration was the concepts proposed by information theorists such as Ash (8), Young (9), and Ashby (10). The solution of the problem involved integrating these viewpoints and concepts with the mathematical theories of the nature of Markoff Chains (11, 12, 13). The proposition was that the long term memory has information stored in discrete units. If true, then a sequence of human behaviors would simulate a special property of Markoff Chains.

The proposition was tested in a year and one half of special treatments of behavior data. Ninety data matrices of coded behavior were each raised to higher powers on an IBM 360/50 computer. A special program for matrix multiplication was devised for the task of "driving" matrices of dimensions as great as 40 by 40. The five power levels (2 through 65,536) of the behavior matrices were each quantified by algorithms of the model. All 90 matrices reached a steady state condition where the links of the chain became independent of each other. Further study provided a proof that certain old theorems were altered as an effect of the steady state condition. Nine new theorems were then devised to define the properties of behavior units in a matrix in a steady state condition. Finally, the long term memory area of the memory model was used in interpreting findings of learning behavior experiments. Eighteen experiments were done to test the model development, and in every instance it was found the theory of the information flow in the long term memory was quite valid. The evidence for this claim is discussed in principles two, eight, and nine in the proceedings.

The more recent work by PIMM has been to broaden the psychological verifications of the model by conducting experiments on three kinds of human tasks in learning. One kind involved tasks of object enumerating and sorting in a visual modality, and with immediate and delayed cognitions. In addition, instructional components have been employed in some of these experiments. Another kind of experiment was conducted for electric circuit problem solving tasks. These emphasized ages of subjects, perceptual instances, and effects of instruction. The third kind of experiment was to study the processing of abstract cognitions with emphasis on the modalities used in learning tasks. In the past year, 17 experiments, involving 2,026 human participants, have been conducted to collect data for the testing of the memory model. Variations of task processing, learning strategems, human traits, and environments warranted the large number of experiments. Some of these are described in the proceedings of this symposium.

The members of PIMM have detected problems in humans understanding the efforts of the projects. The feeling is somewhat of Alfie being our student. We recognize and sympathize with the researcher who has been "following" events in PIMM. The proceedings of this symposium were designed to facilitate grasping the importance of the PIMM endeavour.

The following text is divided into two sections. The first one is an expository statement of the model, and a rationale is presented at a layman level. The technical terminology of model theorems and algorithms have been translated into a language of behavior, structure of behavior, and behavior spuriousness. Psychological learning principles are enumerated and discussed with contexts of experiments conducted by PIMM. The statistical verbiage of research reports have been kept to a minimum so the lay reader may get a "panoramic" view of the model as it applies to understanding how humans learn. Should the reader desire research data of these experiments, we shall be glad to provide it on request. The second section of contributed papers are technical treatments for experiments testing the model. Researchers who are interested in the model are urged to read both sections of the paper.

The contemporary researcher of learning behavior may note a discrepancy in the proceedings of this symposium. Most researchers are advocates of particular schools of learning and expect research reports to identify with a school. The memory model has been found to have principal references for each of the schools. The fact that principles eight and nine refer to the Piagetian School of Learning does not mean any bias exists regarding PIMM. In fact, PIMM welcomes communications with members of the schools who may contribute to enlightenments of school principles being reinforced by the model definitions of human learning behaviors.

The final note in this overview is to ask what it all means regarding the knowledge of how humans learn. PIMM has a viewpoint which is hoped will become yours after reading the proceedings. In order to keep an open mind it is important to note the extent of the success in testing the validity and reliability of the model. It has been tested in 38 learning behavior experiments. In every experiment it has been found to have statistically significant relationships with the properties of the learning task, variables of external factors such as intelligence, strategems of task processing such as memory recall and problem solving, kinds of cognitions such as immediate and delayed, and perceptional conditions such as visual and auditory modalities. The applicability to age and maturation groups of children has been found feasible for difference interpretations in numerous experiments of the same kinds of tasks. It is well known that problems exist in replicating education research experiments. However, PIMM has replicated the same experiment nine times. Principle nine describes an example of the replicability of the qualities of the memory model.

This symposium represents a landmark to PIMM. A new thrust has been adopted for the future. The model will be tested in a carefully controlled series of experiments which will be designed to revolutionize man's understanding of how the human memory actually operates.

MODEL

One of the major problems in education is understanding how humans learn. Several theories of learning have been proposed, but few have complete enough an array of corollaries to be very useful to pedagogists. Researchers have attempted to advance the values of the theories in the teaching of materials to children. The approaches have been to measure behaviors before and after the children have experienced a learning treatment. The measurements have been descriptions of the behaviors, and usually these are researcher constructed instruments. The attributes of the instruments have been concept mastery, memory achievement, and problem solving success scales. These research practices are faulty, if not largely worthless.

The real nature of learning by humans cannot be discovered until the research designs are reoriented and the data of observations are more closely matched to behaviors. Both changes are inclusively similar to philosophy. The exact behaviors must be recorded as the subject executes them. Every behavior must be recorded in the sequence of the history of the output of them by the human. Paper and pencil tests do not obtain such data, only the results of many ensuing cognitions by the human. Data from a study of learning must be recorded as the human is making each overt action in a normal learning experience.

There are major kinds of learning tasks which humans encounter in research experiments. Fortunately these kinds are too easily categorized because they are constructed by other humans. Researchers have commonly constructed recognition, memory recall and problem solving tasks. Unfortunately, the subjects have not always developed mind sets which identify the task as that kind originally labelled by the researchers. For instance, a child may be given a passage to read and then be asked to answer a question. The child might regard the passage as a problem even before he or she discovers the question at the end of the passage. Researchers cannot easily know the dissonance of such a mind style held by the subject unless he asks the subject. Once the question is asked a cue situation contaminates the whole experiment.

Sequential learning experiments have not been properly conducted because the behavior arrays could not be adequately recorded as data. For example, how does one measure the way a child solves an electric circuit problem after he or she has been instructed on how to trace complete circuits. Or if a child is given a series of written passages, over a period of time, how can data be obtained which describes what was learned from reading each passage and what was accumulatively learned from reading the sequence of passages and thinking about them. The standard answer to these research problems has been to administer a test at various stages and to ascertain how much the child has learned. However, each of the tests serves as a cue to the child, and can even provide associational cognitions in the memory.

What is needed in research on learning is a revolutionary reorganization of design and of behavior description practices. A new model needs to be constructed on the basis of the nature of learning and learning behavior. The pedagogical aspect of learning research must be done in the cast of the learning environments set in education institutions. New pedagogy approaches should be attempted, but they too must be constrained to the learning behaviors of humans.

A model for humans learning which is based on descriptions of human behavior can be so narrowly drawn as to be rejected by some researchers. The several approaches of past models have suffered because they satisfied only some of the learning research groups. Researchers of the schools of Ausubel, Gagne, Piaget, and Bruner have not yet been given enough corresponding justification to accept a new theory or one of a concilliatory nature. The other specialists in physiology and psychology have also developed biases regarding new models. This knot of viewpoints has brought forth a new group of model builders. The artificial intelligence people, busily doing computerized simulations of behavior ensembles, are trying to incorporate the psychological principles and physiological mechanisms into models (for example, see 14 and 15). Even the researchers of various name-labelled schools are exploring computer approaches (16).

The question of a model comes down to a description of the overt behaviors of humans and a corresponding description of the processes in the human memory. Both descriptions must be for simultaneously, or matched sequences of successions, occurring actions. The contemporary schools of learning seem to explain overt behaviors in philosophic terms and not of the real memory processes. The causal mechanisms of the memory processes are labelled with descriptive terms, such as assimilation, subsumption, and equilibration. Another school takes a behavioristic approach as the explanation for causal mechanisms. That school is at least honest in concentrating on an invented hierarchy of externalized tasks and the experiences of humans in conducting the kinds of learning tasks.

Humans are not machines but man has constructed machines which he has made human-like in their actions. The mechanistic approach for describing human learning activities and memory processing is probably the most easily understood by researchers. Humans receive information data from the environment. The input channels are through the sensory system, and one cannot now take into account an extrasensory channel. These input channels, or modalities, are usually of a visual or auditory kind, or a combination of them. The output channels which concern learning researchers are vocal and manual. Humans output information in words, which are spoken or written, or manually handle objects as information signals to the research observer.

The researcher constructs an external environment which broadcasts information to the learner or human receiver. Knowing the structure of the information which was broadcast, the researcher waits to observe the output behavior and to code it as information corresponding to the original information. The difference in the two sets of information data are calculated and is called what was learned. The intervening scenario of memory processing is explained as accomodation or subsumption. Differences in kinds of tasks is defined as an a posteriori event which can be explained by the history of the humans' past experiences and the structural complexities of the experiment information.

What is wrong with the previously described model? The structure of the experiment information cannot be quantitatively defined. The modalities of input cannot be traced as to the amounts of information traveling via each kind of channel. The output cannot be put into quantitative data which corresponds to what is known about the physiology of the brain. A new model must account for each of those problem areas. Until that is done, there cannot be a conciliation of the two groups of learning researchers. The schools of learning concentrate on the information inputs and outputs and the artificial intelligence people deal with "explaining" the intervening processes. Neither of the two groups will ever be tested for the veracity of their models because of the discontinuity of their descriptions of total learning behavior.

The model proposed in this symposium is one which can be used to describe all three stages of behavior processes. Furthermore, portions of the psychological and "artificial intelligence" schools are incorporated into the operations of the model. The artificial intelligence group may believe the model is one of theirs but we don't consider membership to be a real one. It is true the mechanistic components may seem to betray our position. However, there is some physiological support for our approach to describing memory processes.

A conceptual scheme has been emerging from recent brain research. Deutsch (17) studied tonal pitch discrimination and concluded that "the pitch memory store is arranged logarithmically in a highly ordered and specific fashion". Wickelgren (18) reported that cat colliculi cells receive and integrate visual and auditory information. Trehub (19) has reported evidence that visual representations are operated on in Fourier Series in the brain. Wiener's (20) autocorrelation system equations have been recently found to operate in neural activity and several researchers have found neuronal activity loops operating in the brain. The long and short term memory stores seem to be able to operate independently and simultaneously (21). These claims indicate the human memory is either (1) a machine, (2) can be described as a machine, or (3) is being described in terms of an operating machine. Regardless of the position one takes, the description of the memory must involve qualities of storage data and quantities of processing actions. Miller's (4) "chunking" principle has survived many psychological tests. Simon (22) recently supported Miller by claiming that research indicates the "chunk" level is operated in terms of the mental maturity of children. The percept for a learning model then is for a quantitatively described system or pattern of memory processes.

The learning schools have a multitude of differences in their means of describing information input and output. They do, however, seem to agree that an environment task does have content and structure. Therefore, in order to have a conciliatory outcome, the model must describe the content and structure of the learning task and behavior output. Nevertheless, there seems to be one concept which has eluded the proponents of the learning schools. It is claimed that normal human behaviors, treated as a sequence of behaviors, are Markovian. This is a subtle consideration but has a major importance in the research of learning behaviors. Very simply it means there is a stochastic dependence between the observed behaviors of a human who is engaged in processing a learning task. One possible explanation for this omission is that, heretofore, researchers have not attended to gathering data which describes the complete continuum of the behaviors of a processed task.

The concept of the Markoff Chain of human behavior has been extensively studied by PIMM at the University of Pittsburgh. Verbal and non-verbal behaviors have been coded in recognition, memory recall, and problem solving kinds of tasks. The behavior codes were placed in a matrix, as a Markoff Chain is a sequence of event data. These matrices were raised to powers by self-multiplication algorithms. The matrices, of dimensions as high as 40 by 40, were then tested for a steady state. The principle of Markoff Chain steady states (11) is that a stationary condition will be obtained at some raised power. This procedure is a valuable test for the validity of the coding of the continuum of human behavior. In PIMM, whenever a steady state was not obtained, an examination of the data revealed the behaviors were discontinuous. For example, a task involving a circuit board was given to children and their actions to illuminate a set of lights by closing switches were recorded. However, the behavior continuity was lacking because some uncertainty operated in the behaviors. The uncertainties were due to the hidden circuity behind the board panel. The interchange of an incomplete physical field of perception and erratic behavior sequences could not be recorded into a complete, and discrete, sequence of behavior codes.

The Markoff Chain concept of behavior data raises a major research problem. The behaviors of humans, being dependent (the Y action depends upon the X action), means the data needs to be tested on a nonparametric basis. The importance of such a statistical approach is discussed in Section Two, page 34.

Some points of connection need to be considered at this point. Assume that the behaviors of a learning experiment have been correctly recorded and that the record is a complete continuum of the behaviors of the human processing the task. The matrix power treatment for a steady state condition will reveal a major finding. At steady state the X behavior becomes independent of the Y behavior. This condition could be considered as related to memory processing. The argument could be that the condition describes the retrieval aspect of the memory storage processes. Several authorities (5,6) have described the match process as being a means for an "identity" between the input information and stored information so an output message or action can be constructed. The steady state could be regarded as an interruption condition, or as the information retrieved from the memory stores.

The structure of the sequence of behaviors in a learning task experiment is a critical issue in research studies. Few if any researchers quantify the structure aspect. It is, however, the sum or total quality of the sequence of behaviors. The nature of the structure is exemplified by the data content of the matrix of coded behaviors. Datum entries in cells of row and column intercepts provide a continuity aspect of pairs of codes. However, the sequencing entries of A to B to C to D, etc. of codes indicate even greater continuity. The occupancies of particular cells of the matrix indicates the kind of distribution of behaviors observed. For example, a sequence of behaviors could have been executed in a step-wise fashion, with no repetition of the steps being done by the subject. The matrix of codes would indicate a diagonal matrix condition. Thus, the structure of the task pattern would be revealed by the density and distribution of codes. What remains for using a Markoff Chain in a matrix is to devise a system for coding behaviors, on a non-weighted basis, and establishing a quantity measure to describe the structure of the matrix content. The degree of structure in matrices and their meanings regarding learning and learned behaviors were studied by the model group at the University of Pittsburgh. The study is described in Section Two, page 48.

Thus far we have considered the model in terms of satisfying the concerns of the artificial intelligence group of researchers. The psychological principles of learning have not been accorded attention. There is a large number of principles, which when constructing a model, one needs to recognize. The principles, do, however, involve the basic percepts of input and output information behaviors. Because of the large number of principles, the model validity is presented in paragraphs which state the principle and tests of the model corresponding to that principle. PIMM has studied 20 principles in the development of the model. Nine of them are discussed in this Symposium.

1) Recall or information output is related to learning experiences.

The structure of human behaviors can be quantified with information theoretic measures. Such behaviors may be of learning tasks or recall cognitions, depending on the experimental design and the system for coding behaviors. Eight of 38 experiments had the recall behavior structure quantified for information flow. Four of these experiments also had input or learning behaviors which were treated for the quality of the structure by quantifying the information flow. The rest of the experiments had the input or learning behaviors treated for the structure of behaviors. Regression analyses of these experiments revealed that the structure of behavior was significantly related to cognition and learning experience behaviors, as well as to input or output score values. The interchange of measurements of structure of behaviors in input and output tasks are exemplified in experiments which define the following principles. The conclusion was that the model defines structures of behaviors whether they be of input or output memory experiences.

2) Humans who receive information through different modalities use different behavior structures in recalling the information.

The experiment involved 114 seventh and eighth grade children of a suburban school. Two groups of children were each presented the same 600 word passage describing radar systems of animals and predation. One group heard it spoken on an audio-tape. The other group read it under controlled conditions. The reading group was allotted a length of time adjusted to their reading ability, as measured by a standardized reading test (see references). Both groups were then given an immediate recall task to write what they had experienced. The recall passages were scored for the terms recorded which had been in the original passage. Then the recall passages of the subjects were term-analyzed and treated to quantify the structure of the behaviors.

The research question was to compare the recall behavior structures of the groups of humans who had received the same information through either auditory or visual modalities. It should be kept in mind that both groups used a written, visual output in the recall task. The source passage had a variety of 38 terms. The visual group recalled a significantly larger variety of terms (mean of 19.57). than was done by the auditory group (mean of 16.32 terms). The visual group also used their terms to an extent significantly greater (mean of 66.25 term messages) than was done by the auditory group (mean of 51.04 term messages). The auditory and visual groups did not significantly differ with respect to paragraph meaning achievement scores (see ref) and intelligence quotient (see references). An analysis of the mean values of algorithms which define the structures of behavior showed significant differences between the two groups. Out of ten tests the visual group had six kinds of information flow greater than the flow for the auditory group. The differences were that the visual group had a greater flow of input and output information, and used a greater amount of error correction in processing the information. On the other hand there was a greater amount of spuriousness in the structures of behavior for the auditory group. The auditory group also had a greater amount of coded information per input information in the short term memory store.

Two regression analyses were conducted to determine the differences of relationships of behavior structures with the recall of variety of terms. These analyses were step-wise regressions (BMDO-2R) and last-load regression (DAMO-3). The step-wise regression load showed that the information flow defining the structures of behavior in recalling were different for forecasting the variety output by the two modality groups. The major information flow forecaster of variety variance for the auditory group was how the humans coded information received from the ongoing task of writing the recall passages. On the other hand the visual group had major forecasters which involved spuriousness in the long term memory store, the relationship of input information to a code factor, the information processed in the short term memory store, and the strength of dependence between processed behaviors. The last-load regression analysis revealed that 11 information flow algorithms and intelligence quotient could collectively forecast 96% of the variance of variety recall by the auditory group and 99% of the variance of variety recall by the visual group. Durbin-Watson Statistic (23) values for these analyses were very similar for the two groups' behaviors and indicated the loadings were non-serial.

Simple linear regression analyses were used to test the relationships of the structure of behavior to the intelligence quotient. Ten of the 27 structure algorithms values were significantly correlated for the visual group and only 3 coefficients of correlation were significant for the auditory group. It could be interpreted that the intelligence quotient was more related to behavior structures of the human of the visual group than to those of the auditory group. This interpretation is supported by the finding that where an algorithm value was found to be significantly correlated to intelligence quotient for both groups, the highest coefficient occurred for the visual group. The intellect trait was related to visual learning by the structure behavior information flow properties of input information, the coding of information, useful information in the STM*, output information, the sharing of information by consecutive behaviors in the STM and the LTM* and the error correction information in the LTM.

The conclusions for this experiment are both revolutionary and puzzling. The quality of the behavior structures which were quantified were of recall cognitions. The recall task was processed by writing what had been experienced in a learning task. The recall output was controlled to be of a visual feedback modality. That is, the humans could use their eyes to

*Acronyms for the short term memory and for the long term memory store.

receive information of what they were writing in their recall behaviors. The experimental variables were the means by which the two groups of humans acquired the information in the learning experience. One group heard the content passage and input information by the auditory modality. The other group read the content passage and input information by the visual modality.

The visual modality group was able to recall a greater number of the different terms (variety) than was done by the auditory modality group. Therefore, the two groups had differing levels of cognition which must have depended on the modality employed for receiving information in a learning experience. It was not a function of intelligence or ability to comprehend paragraph meaning, or level of literacy. The question was how to account for differences in cognition for groups of humans receiving information by different modalities.

The two experimental groups were found to differ in the structure of their recall behaviors. The differences were how the humans processed information in completing the recall task. This discovery, in itself, is a major contribution to the study of learning. However, a puzzle still remains to be solved. The information flow which describes the structure of recall behaviors was different for the two groups of humans. However, as both groups recalled verbal messages they could use their eyes to read what they had written. The word matrix of what was written defines the sequence of outputs from the human memory. The algorithms of information flow define the structure of that matrix, or structure of output behaviors. When the researcher gets large numbers of significant relationships of behavior structure with the words recalled from the learning experience and with the intellect, or intelligence quotient, what should be the conclusion? There is one interpretation which could be advanced for consideration.

The structure of recall behaviors are measurements of the nature of the information stored in the human memory. The argument could be that a human can recall only what was stored. What is stored in the human memory is related to what was perceptionally experienced and concept-processed in the human memory. The logic of this argument can be tested. The source passage was term analyzed and quantified to define its structure of information. The useful information algorithm, believed to be related to the long term memory store, was used for the model test. The recall behavior data, for the same algorithm, of the auditory group was selected for treatment. It was hypothesized that the useful information of the information source (passage) was partially received through the auditory modality of this group of humans. The treatment was to calculate the difference between the useful information flow of the source passage and the output recall behaviors of the auditory groups of humans. The coefficient of correlation between these measurement data and the variety of terms recalled by the auditory group was found to be significant (rxy of -0.55). The interpretation was that, as there was a decreased difference of useful long term memory information and the useful information received in the learning experience, there was an increase in the number of different words which could be recalled. Then a simple regression analysis was made between the variety of words recalled and the LTM useful information in the recall behavior structure. This coefficient of correlation was found to be of the same significant value. However, it was a positive correlation. This could be interpreted to mean that, as there was an increase of the LTM useful information flow, there was an increase in the different words recalled by the humans. The dependent variable for both regressions was the recall variety. In one case the independent variable was a function of what had been received from a source and recalled as useful LTM information. One of the slope ratios was a decrease in differences between the received and recalled useful information and the other was for an increase of recalled information, as there were increases in the recall of different words from the human memory. To put it another way, as the difference between the useful information stored in the memory and useful information output in a recall task decrease, there is an increase in the number of different words that can be recalled from a learning experience. The increase of useful information output in a recall action results in an increase in the number of different words which can be recalled from a learning experience. Is it possible that what was really quantified is the information which was stored in the human memory and later retrieved by a visual feedback of what had been retrieved? This is not an isolated finding or is it an unfound interpretation. The rationale is supported by the studies described in principles four, seven and nine.

3) Instances obtained in the solving of a problem affect the memory process involved in human behavior.

Children involved in solving a parallel circuit problem are influenced by the number of times they test the inference of their solution. This variable, as a positive or negative instance, was found to be a forecaster of potential of success in solving the problem. More importantly, the instance variable was found to be related to the information flow in the structure of behaviors of the children. The study of children of grades one through twelve is described in the contributed paper on page 38.

4) The structure and content of an information source is related to the information obtained from memory cognition.

In this kind of experiment the subjects were given a written or spoken passage for information on a topic. The passage structure was quantified. The subjects then wrote or spoke a recall of the passage. The structure of the recall output was also quantified. Later, the same subjects (N of 46 adults) were given a new and different learning task. For example, they were given a non-word visual object sorting kind of task. Subsequently, the subjects recalled the objects displayed in the sorting task. The structure of the practice learning in the sorting task was quantified. The design now had four phases. The phases with quantified structures were the passage source, a recall of the passage source, and a sequence of behaviors enacted in sorting visual objects. The other phase was a score for the recall cognition in the second task. A statistical treatment of the values of the three structures showed they were significantly related. The relationship was that of the difference between the structure value of the first task information source (passage) and the structure of the recall in the second task. Quite simply the amount of information received in a learning task and recalled from that learning experience is directly related to a haman's ability to have a cognition in still another kind of learning task. One can easily assign another meaning to the results of these experiments. The structure value of the behavior sets are actually isolates of the degree of memory processing occurring in the brains of the human subjects.

The results of another experiment reinforced the claim of isolating the structure of memory processes. College undergraduates (N values of 17 and 19) were instructed on how to solve an electric circuit problem. Later, the subjects were asked to write a passage recalling the instruction. Then they were given a set of concrete objects to use in constructing kinds of parallel circuits. The structure of the instruction and the recall statements of the subjects were quantified. The groups of subjects who succeeded in solving the problem had significant correlations between the differences of the source (instructor) and recall structures of information and the score on their recall of information. There was no relationship found for those who failed to solve the electric circuit problem. One could conclude that success in problem solving is related to a "meaningful" measured learning experience.

5) <u>Standardized measurements of intelligence and achievement are related to only some kinds of learning behaviors.</u>

The supposed measurement of intelligence by I.Q. types of scores and tests are not of value for predicting potentials of humans in processing recognition and problem solving kinds of tasks. Such measurements are related to the memory recall kind of human behavior. The evidence for this claim is from 11 experiments which were of special designs to explore such relationships. In order to discover the intellect quality and its' relationship to task processing, humans had to engage in more than one task and do different kinds of tasks. The behavior sets of each person doing a task were placed in a matrix. The matrices were each quantified for their degree of structure. Regression analyses were conducted to test the relationship of intelligence values to structure values. Significant linear relationships were found only for memory recall kinds of tasks. We are presently studying the data of the experiments as we suspect non-linear relationships may exist. The standardized measurement instruments include Intelligence Quotient (Otis and Stanford-Binet), Miller Analogies Test, Shipley Test (Abstract Form), Iowa Tests of Basic Skills (Map Reading, Reading Graphs and Tables, Mathematics Problem Solving, Mathematics Total, and Composite Score), and the Stanford Achievement Test (Form W, Science Achievement, Arithmetic Concepts, and Paragraph Meaning).

6) <u>Task processing strategies of human behavior can be identified by the structure spuriousness concept.</u>

It was previously mentioned that humans confronted with a particular kind of task may not perceive or process the task as the kind originally conceived by the researcher or pedagogist. This finding was studied with two kinds of experimental designs. Both involved a special property of Markoff structures of behavior patterns. It is very easy to quantify the degree of spuriousness of input and output information in the structure. Humans who process a large number of different kinds of tasks (as many as eight tasks) each have a specific range of spurious information. An informal observation is that females generally have a higher average of spuriousness of information. Furthermore, adults who behave erratically have wider ranges of spuriousness of information. In fact, such a relationship is seen in the processing of successful problem solutions. The second design approach was to administer particular kinds of tasks to large numbers of humans of differing characteristics (e.g. sex, age, mental maturity, and processing modality).

The results of these 30 studies for spuriousness of information in behavior structure has provided us with criteria for defining learning tasks. The range scale, which is now regarded as very reliable, has some overlap for tasks. This seems to be due to individual differences. Spuriousness of information can be expressed in percentage values. These values are 5% to 20% of structure for recognition tasks, 20% to 32% for memory recall tasks, and 32% up for problem solving tasks. Several interesting diagnostics are found for the scale:

a) A test for Markovian behavior is that the input spuriousness is always less in value (percent) than the spuriousness in the output information. The reason for this phenomenon is not yet well understood.

b) The success potential for humans to solve problems decreases as the percentage of spurious information in the structure increases. This is quite logical because the counterpart of spuriousness is a measurement of the useful information quality of the behavior structure. Particular kinds of useful information input and output in the memory seems to be requisite to success in task processing.

c) Children who process a problem solving task tend to increase the spurious level as there is an increase in the level of mental maturation. This corollary will be discussed in principle nine, page 27.

d) Incongruity of human perception and the kind of task being processed usually results in low success problem solving. For example, those humans who have a behavior structure in a memory recall range and are processing what is regarded as a problem (such as the electric circuit problem) usually are unsuccessful.

e) Successive learning experiences in a low level problem solving task result in a decrease in the level of spurious information in later behavior structures of the processing of the problem. This discovery is logical when it is realized that such learning involves an increase in the useful information in subsequent learning behaviors. This corollary is discussed in principle seven.

f) Memory recall has been found to be related to standardized intelligence kinds of test scores. So too are intelligence quotients related to the spuriousness measure. In six experiments we have found significant correlations of spuriousness and intelligence quotient. The regression intercept for spuriousness always was found to be between 18% and 22% of spuriousness of structure for the behaviors of the group of humans processing the memory recall task. The interpretation could be that, when there is no intellect, memory retrieval has a spuriousness of structure of about 20%. It follows that recognition memory processing does not involve the intellect, as measured by intelligence kinds of tests. PIMM has a group of researchers pursuing this problem.

g) Children at the pre-operational level of mental maturity differ from operational level children in learning and cognition behaviors in visual space tasks. Three groups of children, from kindergarten, and grades four and eight, were given a photographic display of objects in a living room. Each child verbally enumerated what they saw in the photograph projection. Later, they verbally recalled the objects in the photograph. Finally, the children were given 20 randomly drawn miniature cut-outs of the objects. They placed these objects on a paper outline of the living room. This spatial location task was scored for correctness of geographic placement. The spuriousness of structures were calculated for the behaviors of the enumerating task and the verbal recall task. The spuriousness values were found to be significantly related to the spatial location scores of the groups of children. The spatial location scores increased as age levels increased (mean values of 7.3, 10.7, and 11.8, respectively). The levels of spuriousness percentages decreased (to differences of less than one percentage point for grades 4 and 8) between the practice experience and recall structures. In fact, the average difference was 9.8 percentage points for the kindergarten group of children. In each sample, the spuriousness in the behavior structure increased from the practice or enumerating experience to that of the verbal recall experience.

7) Successive learning and recall experiences have behaviors which are directly related to the information flow in the behavior structure.

There are several model algorithms which can be used to describe properties of the structure of a set of behaviors. Several experiments have been done with a classification sorting kind of task. Other tasks are now being tested in experiments. However, there is enough evidence to report the principle of immediate and delayed cognition memory processing.

The adult subjects were presented a display of 14 geometric objects (triangles, squares and circles) which were colored (red, blue, green, and black) and labelled with an identity number (randomly assigned integers of 2 through 19). The subjects were given 11 minutes to write the identities (number label) of objects in sets which have common properties. The 16 subjects were later asked to spatially locate and identify the objects in the display (referred to as Recall # 1). A week later the same subjects were asked to recall the objects and to spatially locate and identify them (referred to as Recall #2). Two hours later they were given the practice learning experience of sorting the objects and an immediate recall task (referred to as Recall #3). The structures of the two sets of pattern behaviors in the practice learning experience were quantified by coding the set entry elements into a matrix (one matrix for each practice learning experience).

It was hypothesized that the structure of the learning behaviors was related to delayed and immediate cognitions for the same kind of task. Cognition was defined to be the spatial location and the attribute identifications of the objects (shape, color, and identity number). A maximum of 42 was possible for a recall score (after a correct quadrant location, each property of shape, color, and number label was enumerated). The average recall in the first immediate recall score was 14.25 (two "chunks"). After a delay of one week, the average score was 11.38 (Recall #2). The average score was 21.9 for the second immediate recall (Recall #3).

An examination of the elements which were recalled was quite interesting. An average of 7.25 elements were common to recall tasks one and two. An average of 6.69 elements were common to recall experiences one, two, and three. An average of 8.56 elements were new in the third recall experience. These recall values seemed to indicate that "chunking" and associational learning was occurring.

Over 300 regression analysis tests were conducted to determine the relationships of structural properties of information flow with cognitions. Three major findings were obtained from the analysis

Eight different information flow measures of the two learning experiences were significantly correlated. These measures had to do with the degree of spuriousness of information flow in the behavior structures and the amount of input information which was coded for channel information "transmission".

The second finding was that the change in levels of cognition between the three successive recall experiences were related to each other as well as to the properties of information flow in the structures of the learning tasks. Several examples can explicate this major finding. The cognition in recall task number two (delayed recall), consisting of the elements of task one and two which were not common, was significantly related to the degree of spurious structure in the first practice learning experience. The intercept for the regression test was a 12.7% level of spuriousness, indicating cognition originated in the recognition region of memory processing (see principle six above). The relationship of the structures in the two practice learning experiences was by the degrees of spuriousness in the two learning behavior structures. The regression intercept for the spuriousness for the second learning process, when there would be no spuriousness in the first experience, was 15.9%. Again we see a level of recognition cognitive behavior as the "beginning point" of the degree of spuriousness in the structure of behaviors. The mean averages for the two tasks were 35% and 34% of spuriousness, respectively. The memory processing range then "moves" from a recognition phase to that of a low level problem solving process (see principle six for a description of spuriousness levels which define kinds of task processing).

The third finding involved a study of the attributes of the task. The major attributes were the shape, color and identity numbers of the 14 displayed objects. Regression analysis of the recalling of attributes showed significant relationships for the sequences of cognition. For example, the number of shape elements retrieved in the first recall task were related to the number of new shapes in the delayed recall task (Recall #2). The number attribute of task one was significantly correlated to the recall of task three number attributes.

Color was a more intricately processed attribute. The recall of color in task one was related to the old (or color elements recalled in tasks one and two) color elements and to the new color elements in task two (delayed recall). The problem then for a cognition of color attributes in a delayed recall seemed to be one of a kind of long term memory storage of the colors of the 14 figures in the learning display. The question was then, how could the structure of the learning behaviors (in the first practice learning task) be related to the delayed recall task, or more specifically, what had to be recalled from the long term memory stores of the human brain. The discovery of an answer to the question was quite revolutionary, but very logical.

There are several quantitative measures of the structure which are collectively called steady state information flow measures. It was explained on page 4 that the Markovian matrices of behaviors can be "driven" to conditions where the elements of behavior are no longer in a related sequence, but are "separated" from each other. It was inferred that this condition could be a description of the long term memory store. If this was the case, these kinds of information flow measures should be related to the cognition in a delayed recall task, and which occurred one week after the initial learning experience. The old, or color elements common to the first recall and the second delayed recall, were significantly correlated with five different measures of steady state information flow. The question of how such an aspect of the structure was linearly related confronted us. The solution was that the total number of color elements recalled in task two was correlated with a special measure of information flow. This measure is considered to represent the input information received in a learning task and then stored in the human memory. The relationship of the cognition of color elements in the third recall task to previous cognitions was quite different. The old elements of the second recall task was significantly correlated with the old color elements recalled in task three. This sequence of "causal" relationships is a major breakthrough for the veracity of the model. Quite simply, the information stored in the long term memory was quantitatively described by measures of the model. Furthermore, and quite importantly, this correspondence was directly related to the information retrieved from the long term memory and then output during a delayed recall task.

One final point should be mentioned for this relationship of the model structure of behaviors and cognition. There is probably a complex of comparators in the human brain which moderates the pathways of information retrieval. Sternberg (6) has postulated the existence of such a processor. The change of cognition levels for the attributes of shape, color and number were found to be significantly correlated with three different kinds of information flow measures. Twenty-two different measures for the information flow in the structure of the cognitive behaviors were regression analyzed. Fourteen of the measures of the first practice experiences of learning behaviors and five of the second practice experience measures were found to be significantly correlated to change in the levels of cognition. In other words, the test of relationships of the measures of information flow with the total cognition changes for the three recall tasks were significant. The degree of significance was greater for the first learning experience than for that of the second learning experience.

The significant correlations were of measures of information flow in the original matrix condition, and not for the previously mentioned information measures of the steady state condition. A refinement of the analysis of cognition elements into shape, color and number attributes was found to be the same as that for the total scores of cognition. In other words, the changes in attributes are correspondent with changes of total cognitions. Both actions, being similarly related to information flow measures, could mean that the comparator of the human brain operates as a loop of information transmission through the short term memory store.

8) Visual sorting of subjects and cognition of locations of spatial representations are related to the mental maturation of humans and the structure of their learning behaviors.

The visual sorting experiment described in the preceding principle was conducted with suburban school children of grades two, four, six and ten. The design variation was that the children experienced the first phase, consisting of a practice learning experience and an immediate recall task. The practice of set formations of the 207 children was categorized as to the reason for each formation. One of the categories was the use of two or more object attributes (such as size, shape, color,etc.) for the formation of a set. The proportion of the groups of grade level children who practiced "attributes" increased as there was an increase in grade level. The respective percentages of grade level groups were: 6.2 (2nd), 39.0 (4th), 42.6 (6th) and 56.6 (10th). These proportions could be interpreted to have some implications about the mental maturation of the children participating in the experiment.

The interpretation of how humans sort elements and then have a recall cognition is very complex. Not only did the age groups differ in the practicing of attributes, but there was also an innovation in the using of patterns of the display for forming sets at the sixth grade level. The number of the elements recalled also differed for the age groups. The grade groups recalled an average of 10.1 (2nd), 11.4 (4th), 12.9 (6th), 16.8 (10th) elements in the immediate recall task. However, the number of sets the group formed in the practice learning experience was not in an ordered fashion. The average number of sets were 8.2 (2nd), 14.0 (4th), 10.1 (6th), 18.0 (10th). There was not a direct increase in the recording of set entries. The entry averages were 34.8 (2nd), 59.6 (4th), 50.3 (6th), 77.7 (10th).

The practice learning experience of set constructions involved six kinds of reasons for set formations: shape, color, number, attributes, pattern, and for other reasons. The recall task involved memory retrievals of the shape, color and number elements. These sub-scores can be used for a total score (a possible maximum of 42, or 14 objects times 3 attributes). In addition, the experiment design included external variables. These were the number of sets, number of set entries, intelligence quotient, as well as the Shipley Test (Abstract Form) for the sixth and tenth grade groups. The experimental design involved these 14 variables for analyzing how humans process the learning and cognition recall task.

The structure of behavior actions in the learning experience was calculated for each child. This treatment was quite complicated, as it involved the use of 23 algorithms for measuring the information flow in the experience for learning. Seventeen of these algorithms were for the original matrix structure and five were for the aforementioned steady state condition of the structure (see page 4 for the discussion of steady state). The other one was for the strength of dependence between behaviors.

Three statistical treatments of the data were conducted to test the significances of relationships. These treatments involved simple correlations, step-wise multiple regression analyses, and last-load multiple regression analyses. This means that 3,588 coefficients of correlation were calculated in statistical treatments. Then the groups of grades four, six and ten were treated as to last-load regression analysis for those who did or did not practice attributes. This involved another array of 3,680 coefficients of correlation. Consequently, the researcher was confronted with interpreting 7,268 coefficients of correlations for the regression analysis of how children had practice sorting experiences for learning and recall cognitions. A unique system of pattern analysis was used to establish the characteristics of age levels of children and the structure of their behaviors in the learning and memory processing of the task. The relationship of the flow of information in the structure of the behaviors for children of different age levels and the possibility of determining levels of mental maturation was tested by a two-step analysis. Table One shows the average scores for elements recalled and the number of elements practiced, as reasons for set formations, in the learning behavior phase of the experiment.

The shape element was the only attribute of the sorting display which was recalled in increasing numbers as the ages of the groups of children increased. The recall of the color attribute increased to grade four and then remained relatively stable. The recall of the number attribute was relatively "even" for the first three grade level groups, and then increased to 5.1 elements recalled by the tenth grade group.

The practice of sets for shape reasons separated into two levels. The second and fourth grade groups practiced about one less set than the number of elements recalled. On the other hand, the sixth-and-tenth grade groups recalled about twice as many shape elements than they used for reasons in the formation of sets in the practice learning experience. The groups all practiced more color sets than the number of color elements recalled by them. The relationship of practice sets for number reasons and the amount of number elements fluctuated for the grade level groups.

On the surface there seemed to be a disparity in the ways in which the groups of children processed the attributes in the learning task and in the way the attributes were recalled as elements. One clue for the explanation was to assume that children who formed practice sets for reasons of two-or-more attributes had different cognitive behaviors than children who did not evoke such behaviors. An examination of Table One shows that such an assumption is quite valid. With only two exceptions, the groups of children who operated with the attribute characteristic had greater numbers of elements recalled in the immediate recall task. The exceptions were where fourth grade children recalled the color element in similar amounts (3.3 elements) and where the group of tenth grade children who did not practice two or more attributes recalled more number elements (5.3) than the group of tenth graders who practiced attributes (4.8). A comparison of sets practiced and elements recalled showed that the group of children who practiced attributes formed the same number or fewer numbers of sets than was the number of attribute elements recalled in the immediate recall experience.

We could then conclude that children of differing ages processed the learning and cognition aspects of the sorting task in different ways. The processing patterns were then due to some difference in mental maturity. This inference was pursued in the two-step analysis. The groups were examined for the use of two or more attributes as reasons for forming sets in the practice learning experience. As shown in Table One, there was an increase in the average number of attributes sets as the age of the children increased. This discovery allowed us to statistically analyze the grade level groups of children for a relationship of the attribute characteristic to the practice and cognition behaviors and to the information flow in the structure of the learning behaviors.

TABLE ONE

MEAN RECALL AND PRACTICE ELEMENTS FOR GRADE LEVELS TWO, FOUR, SIX AND TEN, BY GROUPS OF CHILDREN WHO DID OR DID NOT PRACTICE ATTRIBUTES

GRADE LEVEL	RECALL			PRACTICE			
	SHAPE	COLOR	NUMBER	SHAPE	COLOR	NUMBER	ATTRIBUTE
A-TWO	3.9	2.2	4.1	2.5	2.4	0.7	0.1
FOUR	4.6	3.2	3.7	3.6	4.1	4.2	0.6
SIX	6.2	2.9	4.0	3.2	3.1	2.5	0.7
TEN	8.8	2.9	5.1	4.4	3.7	4.7	1.3
B-FOUR:PRACT. ATTR.	5.2	3.3	3.8	3.1	3.3	3.9	1.4
SIX	7.4	3.6	4.8	3.4	3.2	2.2	1.6
TEN	9.1	3.5	4.8	4.4	3.7	3.3	2.3
C-FOUR:DID NOT PRACT. ATTR.	4.3	3.3	3.6	4.1	4.7	4.3	
SIX	5.4	2.3	3.5	3.1	3.1	2.7	
TEN	8.5	2.2	5.3	4.4	3.7	6.5	

We now had a multi-dimensional analysis situation. The dimensions were (1) two kinds of mental maturity (the practice of attributes and possibly chronological age), (2) the use of four display attributes in a practice experience, and (3) the recall of three display attributes. This complex of parameters was compounded by the criterion that there were differences in the structure of the behaviors of the groups of children. It was previously mentioned that algorithms have been developed to quantitatively define the quality of the structure of human behaviors. The testing of 23 different algorithms in such an analysis was almost impossible. Thus they were grouped for interpretation purposes. Regression analysis tests were computed (in a last-load treatment by the DAM O-3 Program) for all 23 algorithms. Then they were grouped into three levels, on the basis of the three characteristics of the memory. These were the simulations of the short term memory store (Level One), long term memory store (Level Two), and by the strength of dependence between behavior events. The latter factor was tested for differences of information event dependencies by the age and attribute groups. Table Two lists the mean strengths of dependence. It can be seen that differences did exist for the characteristic groups.

TABLE TWO

STRENGTHS OF DEPENDENCY BETWEEN BEHAVIORS IN THE VISUAL SORTING TASK*

GRADE LEVEL	Total		Practiced Attributes		Did Not Practice Attributes	
	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.
TWO	.00097	.00129				
FOUR	.00348	.00294	.00344	.00272	.00350	.00311
SIX	.00340	.00580	.00430	.00814	.00282	.00329
TEN	.00740	.00751	.00581	.00404	.00947	.01020

*Calculated for the 16th power of the matrix condition.

The significant last-load regression coefficients of the analysis were used to determine the relationships of learning and cognition for the attributes of shape, color and number and information flow values in the three aforementioned cells. The presence of significant relationships in the three cells is symbolically noted in Figure One. The interpretations of the findings from Figure One are as follows:

SHAPE a) Grade two practiced and recalled about as well as did grade four. The information flow of practice (P) was almost the same, the difference being that the grade two group had practice-information flow relationships in the LTM*. The basic difference for a greater recall by the fourth grade group was the relationship of cognition to the STM* and strength of dependence between learning behaviors.

b) Grade six recalled elements more than did the grade four group, even though fewer sets were practiced. The difference seems to have been due to a cognition and attributes behavior in the STM. Grades six and ten both practiced about half the number of sets as were the number of elements recalled by each group.

c) Grade ten recalled more shape elements than was recalled by grade six. The grade ten group differences seems to be a relationship of cognition to the strength of dependence between behaviors.

d) The attributes groups differed in recalling shape elements; the groups practicing attributes recalled more elements in each comparison. However, with the exception of equal amounts in grade ten, the groups practicing attributes formed fewer sets for shape reasons than done by the groups which did not practice attributes. As can be seen in Figure One, the difference was that the practicing attributes groups had cognition and attribute relationships with the flow of information.

COLOR a) Grade two practiced and recalled fewer elements than did grade four. The grade four group, however, had multi-level cognition relationships with information flow.

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*STM: Short term memory store, level one in Figure One.

*LTM: Long term memory store, level two in Figure One.

b) Grades four, six, and ten had about equal patterns of practice and recall. They did differ in the relationships of information flow to behaviors. The general affinity was the presence of cognition and attribute relationships.

c) There is not a clear explanation for differences of attributes groups recalling differing numbers of color elements. There was no difference in recalling by grade four. The groups which did not practice attributes in sixth and tenth grades did practice more color sets than they recalled. The information flow relationships did differ in patterns for the attributes groups. The difference was possibly due, in grades four and ten, to the presence of attribute-information flow relationships. In grade six, there seems to have been a difference by there being no practice behavior relationships in the STM. It may be that cognition relationships had a dominating effect, particularly when operating in the STM.

NUMBER a) Grades two and four had similar recall cognition in number elements. The paradox was that grade four practiced more reasons of number set than was recalled as elements, and the group of second graders recalled almost six times more than was practiced. The difference in information flow relationships was the presence of an STM cognition factor.

b) The grade four and six groups differed by grade six recalling more than was practiced. Again the difference seems to be the presence of cognition relationships with information flow in the STM, and probably more importantly, the LTM.

c) Grades six and ten differed by the grade ten recalling more and practicing more than done by grade six. The information flow difference was the cognition presences in the LTM. The case was of single operators for the color and the attributes practice. There seems to be some added value of cognition in the LTM when not having a practice relationship accompanying it.

d) The attributes groups exemplified the roles of the attribute-information flow and the single operator concept. The groups practicing attributes had more efficient recall compared to involvement of practicing number sets. The patterns of difference were that grades four and six groups which practiced attributes recalled more elements and practiced fewer number sets than done by the group which did not practice attributes have attribute-information flow relationships with the strength of dependence between behaviors and the LTM. At the sixth grade level, the idea of practice and cognition being in the LTM exhibited the operator contamination concept. In grade ten, the similarity in recall could be explained by the respective presence of information flow relationships with cognition and attributes factors in the <u>LTM</u>.

FIGURE ONE

Significant Coefficients of Correlation for Information Flow
and Kinds of Forecasters: Levels One, Two
and Strength of Dependence as Dependent Internal Variables

GRADE LEVEL AND PRACTICED ATTRIBUTE CRITERION	SHAPE			COLOR			NUMBER		
	LEVEL ONE[a]	LEVEL TWO[b]	DEPEND-ENCE	LEVEL ONE	LEVEL TWO	DEPEND-ENCE	LEVEL ONE	LEVEL TWO	DEPEND-ENCE
A. TOTAL									
TWO	P[c]	P	P	P	P	P	PC[d]	P	P
FOUR	PC		PC	PC	C	PC	P	P	P
SIX	C*			C			PC	PC	P
TEN	C		C		*		PC	C	P
B. PRACTICED ATT.									
FOUR			P*	PC	P	C*	P		*
SIX	C*			C			P*	P*	P
TEN	C	*	C		*		P	*	
C. DID NOT PRACT. ATTRIBUTES									
FOUR	P			PC	C		P		
SIX	C		P	P	PC		PC	PC	P
TEN	P			C	C		PC	C	

a: Refers to information flow in the short term memory store.
b: Refers to information flow in the long term memory store.
c: Refers to practice learning as an independent variable.
d: Refers to recall of elements as an independent variable.
*: Refers to practice attributes as an independent variable

The role of intelligence in processing the structure of behaviors for the sorting task is intriguing. In some ways it is an indicator of a role in behavior processing as well as the interaction of attributes operations. The significant correlational relationships of intelligence quotient with information flow are listed in Figure Two. The figure also contains significant correlations of the total recall score, the Shipley Test (Abstract Form); administered in grades six and ten), and the number of sets practiced, with information flow in the two levels (STM and LTM) and strength of dependence.

The role of the total number of elements, or total recall score, in information flow relationships was not large. Examine the sub-scores for the attributes of shape, color and number elements in Figure One in order to understand the small role of total recall score. In fact, only nine out of 230 last-load total score coefficients of correlation tests were significant. This is compared to 56 significant correlations (for 230 tests) for intelligence quotient and 72 significant correlations (for 230 tests) for the numbers of sets formed in the practice learning experience. Comparatively speaking, the role of intelligence quotient is "almost" as great as that of the number of sets formed in the practice learning experience.

It is tempting to consider the measured intelligence factor as an indicator of the intellect or memory processing function in human behavior. The relationship of the "intellect" to mental maturation characteristics, such as in this study, could be drawn in terms of the sites of memory processing. These inferences may be seen in the quality of the patterns in Figure Two. The total recall score (S) was related to information flow in the lower grades. The exception was for the sixth grade group which did not practice attributes. Generally, the relationship operates for groups of children in second grade or fourth grade. Scan the levels-of-forecast sections of Figure Two. The section has number entries with "one" indicating that entry which had the highest forecast for the variance of information flow in the structure of behavior. As the grade level increased, the highest "intellect" forecast of information flow variance went from operating in the STM through the LTM, and then to the strength of dependence between behaviors.

Now examine the symbols of Figure One and compare the cognition entries with the level-of-forecast section of Figure Two. Twenty-six of the cognition entries match in level and dependence entries with the entr s of the intellect. Only seven of the cognition entries do not match, and four of these were for the sixth grade group which did not practice attributes.

The Shipley Test measures the abstraction potentials of humans. It is interesting to note that it was criterion matched to the "intellect" in the STM for groups of sixth and tenth grade children who practiced attributes in set formations. The next principle will contain a discussion of the value of this test in diagnosing mental maturation levels.

FIGURE TWO

Significant Coefficients of Correlation for Information Flow and Kinds of Forecasters: Levels One, Two, and Strength of Dependence as Dependent External Variables

		FORECASTS			NO. SIGN. FORECASTS BY I.Q.			
GRADE GROUPS:	TOTAL RECALL SCORE	LEVEL ONE	LEVEL TWO	DEPEND-ENCE	TOTAL NUMBER	LEVEL ONE	LEVEL TWO	DEPEND-ENCE
A. TOTAL								
TWO	10.08	I	I	S	3	1	2	
FOUR	11.41	ISN	N	IN	12	1		5
SIX	12.92	IN	I	N	5	1	5	
TEN	16.81	IN		IN	6	2		1
B. PRACTICED ATTRIBUTES								
FOUR	12.22	ISN	N		3	1		
SIX	15.00	IL		N	4	1		
TEN	17.13	IL		I	2	2		1
D. DID NOT PRACTICE ATTRIBUTES								
FOUR	10.89	N	IN	N	3		1	
SIX	11.00		S		0			
TEN	16.39	IN	I	IN	18	3	1	8

I: intelligence quotient
S: total score in recall
N: number of sets practiced
L: Shipley Test (Abstract) score

This extensive description of one study may seem complex. The findings and interpretations were presented in a qualitative fashion because of the complexity of the experiment. Please note that over 1,900 significant last-load coefficients of correlation were found in one treatment by a multiple regression analysis. The forecast levels of information variance ranged as high as 70 percent. Interactions were tested with the Durbin-Watson Statistic (23). The pathway analysis is in progress for a quantitative interpretation of the data. This preliminary analysis of the findings involved only the significant forecasts and their numbers. Nevertheless, we feel the major interpretations, presented herein, are quite valid.

The basic conclusions of the study were:

a) There is a Piagetian trend in the practice learning behaviors and recall cognition for the sorting task. The attribute of shape is more clearly of this characteristic. The use of two or more attributes in the formation of set increases with age, and reinforces the argument for a Piagetian approach. The conclusive evidence is found in the success in finding differences of age groups which did or did not have the attributes characteristic. Not only did they have differences in learning behaviors, but they also have different cognition outputs.

b) There is a complex of relationships of the information flow of behavior structures which operates for the mental maturation and ages of groups of children. Cognition for information flow is largely a pattern of the roles of strength of dependence between behaviors, attributes, intellect and abstraction potential. Dominance roles for the processing of information through the short and long term memory stores were found as explanations for differences in cognition by mental maturation levels of groups of children.

9) <u>The processing of non-contextual and contextual classification sorting tasks by humans of concrete and formal operational levels are related to the structure of their behaviors.</u>*

This experiment was an extension of the one described in principle eight. The major research question was, given the operational levels of children aged 15 years, is it possible to distinguish behavioral structure changes resulting from instruction in classification sorting? A unique design for the sample treatments was developed on the basis of the Shipley Test (Abstract Form). Three studies were conducted to test the relationship of Piagetian task performances to focus on the Shipley Test. The validity and reliability of five pilot studies encouraged the continuance of the research project.

* The experiment herein describing this principle was conducted by David L. Dunlop.

A population of 375 ninth grade children was administered the Shipley Test. The top 100 and bottom 100, in terms of sex, of the score achievers of concrete and formal operational levels were selected. Fifty males and 50 females were selected from the upper and lower thirds of the score distribution of the 375 subjects. These children were given the 14 object sorting task described in principle eight. Then they processed a practice learning experience and recall cognition for a task involving 14 kinds of animals. A split sample of 50 from each of the two operation levels was then given instruction on sorting procedures. The control was given a placebo statement of instruction. Then the experimental and control samples were given a second sorting task of 14 new animal objects. On the fourth day of the experiment, the samples were given a new task experience. Each group of children was asked to construct an individual sorting task scheme. Then the children were asked to practice their own classification scheme by forming sets of object elements and giving the reasons for each set formation. Immediately following that experience the subjects were asked to recall the criterion elements of their classification scheme.

This experiment afforded the quantification of information flow of behavior structure in several experiences of practice learning. The behavior data for each child were treated for information flow measure values in each of the four practice learning experiences and for their recall of a passage in the instruction of how to do classification sorting or of the placebo statement.

This study is still in progress. However, preliminary analyses do indicate there are several major findings.

a) The study was found to be a replication of that one described in principle eight. A last-load regression analysis (DAM-03) of variables was conducted for each of the five research phases of the experiment. The proportion of significant correlations was found to be 63.7 percent, as compared to a 64.0 percent level in the previously described study. Considering the unreliability of replication in most educational research studies, this outcome of statistical treatments is quite phenomenal.

b) It was mentioned in the study described in principle eight that the children who practiced attributes in set formations provided a criterion for discriminating children of the concrete and formal operational levels. It was reported that the groups of children which practiced attributes had larger average recall scores than the respective groups which did not use attributes for reasons in forming sets. In the present study it was found (see Table Three) that the formal operational groups had significantly higher recall scores than those obtained by the concrete operational groups.

c) The contextualizing of a task, by changing the display objects from geometric figures to pictures of animals, affects the set formation practices and recall cognition behaviors of operational level groups. The contextualization effect caused an increase in the recall of elements. (Examine the averages in Table Three). This increase was greater for the concrete group than for the formal operations group. The recall of shape, color and number elements varied as to the operational level of the groups of children. The recall of shape decreased by 18.0% for the formal group and 7.1% for the concrete operational group. The increased recall of color-name (name was substituted in task two for the color attribute) occurred in corresponding proportions for the two operational level groups. The recall of the identity number of the objects decreased by 45.6% for the formal group and only by 29.6% for the concrete group. The practice of set formation characteristics for the two groups showed shifts of behavior for the two operation groups. The two groups did not differ in the increase of the proportion of sets attributed to the name of the animals, as compared to the color of the objects in task one. The set formations for this attribute label increased by 232.88% and 218.23%, for the respective formal and concrete groups. The concrete operation group had greater decreases in the use of shape and identity number set reasons than done by the formal group. The two operation groups did not differ in their decrease in the use of pattern reasons for set formations. However, the changes in the use of two or more attributes for set formations differed for the two operation groups. The formal group had a 90.1% decrease and the concrete group had only a 25.0% decrease in the use of "attributes" for set formations. The formal group increased the use of "other" reasons by 147.22% for set formations in task two. On the other hand, the concrete group decreased the use of "other" reasons by one quarter.

The conclusion was that abstract (14 geometric objects) and concrete kinds (14 figures of animals) of perceptual tasks are processed in different ways by groups of children in the formal and concrete operational levels. The difference is that concrete operational children can recall more if the object information received by their senses is of a concrete nature. These children tend to practice shape more and use shape for a recall cue to a greater extent than done by formal operations children. They also recall number labels from concrete displays more effectively than done by formal operations children. In addition, the concrete operations children seem to have a relatively monotonic perception of "attributes" characteristics, regardless of the degree of abstractness of the display. In other words, by the abstractness of perception of environment of objects, the concrete operations child has a limit in the use of two or more attributes for forming sets. On the other hand, as displays become more abstract

TABLE THREE

Practice and Recall Characteristics for Tasks
One and Two, by Operation Level

	PERCENTAGES				MEAN VALUES			
	Task #1		Task #2		Task #1		Task #2	
Characteristic	Formal	Concrete	Formal	Concrete	Formal	Concrete	Formal	Concrete
TOTAL Recall					15.30	11.81	16.92	14.30
Recall Shape	49.7%	55.1	36.8	42.3	7.60	6.51	6.23	6.05
Recall Color								
(name in task two)	22.4%	21.4	49.4	44.1	3.42	2.53	8.36	6.30
Recall Number	28.0%	23.5	13.8	13.6	4.28	2.77	2.33	1.95
Practice					17.10	13.93	14.53	11.94
Shape	33.9%	47.7	21.2	22.9	5.80	6.64	3.08	2.73
Color								
(name in task two)	21.7%	26.0	59.9	66.2	3.71	3.62	8.64	7.90
No.	27.2%	16.2	10.7	3.9	4.65	2.25	1.55	0.46
Attr.	5.1%	2.9	0.6	2.5	0.83	0.40	0.08	0.30
Other	2.4%	2.6	3.6	2.7	0.36	0.36	0.53	0.32
Pattern	9.9%	4.7	4.5	1.9	1.70	0.66	0.65	0.23

(the use of geometric figures), formal operations children tend to be more capable in using two or more attributes in formation of sets.

These findings indicate that the contextualizing of information objects in the environment is more beneficial to concrete operational children than it is to formal operational children. However, regardless of the degree of abstractness of the task repertoire, formal operational children can process the information and have a more effective cognition than can concrete operational children.

The aforementioned findings posed a rather revolutionary question. The question was, were these differences manifested in the flow of information in the structure of behaviors.

The mean values of 27 different kinds of information flow were used to test the significance of differences between the concrete and formal groups of children processing the sorting tasks. The t-test results are shown in Table Four . There were more differences between the two groups of children in the flow of information in the contextualized task than occurred in the non-contextualized task. In other words, in task two, 26 of the 27 different information flow quantities were found to have test values for the two groups which were significant at the five percent level. This is compared to only 13 of the 27 flow quantities being significantly different in task one.

The context levels of the two tasks were manifested by the significant differences occurring for different behavior structure levels. The differences between tasks were found to be that the flow in task one was exclusively that of the short term memory store. In the contextualized experience, task two, the differences were in all three behavior structure levels.

The t-test results in Table Four also indicated that there were task-oriented differences in information flow which depended upon the operation level of the children. In every case the formal operation group of children had a greater flow of information than found for the concrete operation group. For example, examine the number of significant t-tests in the short term memory level of task one. The 13 significant tests were distributed with nine of them having greater information flow manifested by the formal operation group than for the concrete operation group.

TABLE FOUR

t-test Results for the Flow of Information for Concrete and Formal Operational Groups of Children in Two Tasks

	TASK ONE			TASK TWO		
	Flow Value Favoring		t-tests significant at 5% level	Flow Value Favoring		t-tests significant at 5% level
Level of Information Flow	Formal Group	Concrete Group		Formal Group	Concrete Group	
Short Term Memory	9	4	13/17	12	4	16/17
Long Term Memory	0	0	0/8	6	3	9/9
Strength of Dependence	0	0	0/1	1	0	1/1

Without going into the results of several analyses of the data of this experiment it should be obvious that several conclusions can be drawn by the reader. It was originally proposed that children of different mental maturation levels differed in the ability to process and recall a sorting task. The operation levels were apriori distinguished by an abstraction test (Shipley Test). The two groups of 15 year old children were given two kinds of sorting learning tasks which were controlled as to content display (14 objects with attributes). The tasks were different as to being "abstract" geometric shapes and being of pictures of animals. The two groups differed as to numbers of reasons for set formations and as to the amounts and kinds of recall cognitions. Furthermore,the contextualization effect was evidenced by different behaviors for the two operation groups. Finally, it was found that these differences were confirmed by differences in the information flow by the two groups of children. Consequently, operation levels of children of the same chronological age may be identified by task processings and cognitions as well as behavior structure characteristics.

Design and Testing Problems in Measuring Information Flow

Willard W. Korth

The basic concepts of the information memory model present a major problem in the statistical treatments of behavior data. The purpose of this paper is to explore the properties of the model and the conditions for selection of tests of statistical significance. Before discussing the problem, the model needs to be more clearly defined.

The Mathematical Theory of Communication developed by Shannon is of two kinds of source information (1). One of these is that there is a continuous source of information and the other is a source of discrete units of information. The memory model is used to describe observed human behavior enabling us to focus on the nature of the discrete source of information theorems. In order to develop these theorems, Shannon (1), proposed several mathematical conditions. He utilized the theory of Markoff Chain processes which were ergodic. This kind of process involves finite states of transition. On the basis of this special kind of mathematical system, Shannon constructed nine theorems for noiseless transmission channels. He then made three more theorems for noisy transmission channels with discrete sources of information. The distinction between these two kinds of channels became the crux of the failure of behavioral scientists to appreciate the potential applicability of Information Theory. The history of this use of the theory was discussed on page 4 . In the following paragraphs we will discuss the subtleties of the mathematical basis of the channel conditions for discrete sources of information.

The behavior data matrix is always a square matrix which has i,j cells for data entries. Each row entry has an intersect location for describing the succeeding behavior. The transition states are then fixed by the sequence of behavior data. Such a construction introduces conditional probabilities for the occurrences of behavior variety.

We now have a Markoff Chain which is described by the very nature of the behavior data. Several mathematicians (8,11) have exhaustively described Markoff Chains but have not completely applied it to learning behavior situations. Shannon approached the application with a study of the approximation orders of word passages. However, he did not pursue that concept to the limits of Markoff processes. Khinchine (24) and Smorodinsky (25) skirted the problem by setting maximal limits for the ergodicity of source information.

The PIMM group attacked the rejuvenation problem of Information Theory and memory models by going back to the basic mathematical properties of Markoff Chain processes. This involved the concept of the matrix, its' Markovicity for data occupancies, and as a tool for calculating information measures. It was discovered that behavior data matrices driven to steady state, had $H(x)$ values approximating those of $H_x(Y)$. Figure Three describes the hierarchical relationship of information flow algorithms. Two main branches operate for the original matrix information measures. These are listed under the heading of short term memory.

FIGURE THREE

Schematic Diagram of the Algorithmic Relationships of Information Flow Measures

SHORT TERM MEMORY				LONG TERM MEMORY		
$H_x(Y)$		$H(X)$		$H(X)$		
$H(Y)$	CODE- - - - - - -		STRENGTH OF DEPEND-ENCE	$H(Y)$		
REAL		$H_y(X)$		REAL	$H_y(X)$	NOISE
	LTM					
				$H(X,Y)$		
	$H(X,Y)$					
					NOISE:X	NOISE:Y
NOISE:Y	NOISE	NOISE:X				

The steady state condition for a Markoff Chain matrix is where the i values become homomorphic in value. According to Feller (11), this invariant condition is attainable only if it is ergodic. We, then have come full circle. The behavior data previously described is in fact Markovian and ergodic. Herein then is the proof of the validity of the information memory model. The practice of assigning information flow algorithms to these data then is a natural application of Shannon's Mathematical Theory of Communication. The PIMM discovery of the relationships of $H(x)$ and $H_x(Y)$ at steady state of Markoff Chains was a major breakthrough. In this condition, according to the Theory of Markoff Chains, the i and j intersects become independent. This being the case, the PIMM analogy for the long term memory information storage and retrieval becomes plausible.

The data use described for Markovian behaviors presents a major problem for researchers. Clearly, the data of the original matrix is not independent. However, at the steady state, it can be assumed that the behavior data is independent. Thus, on the one hand, the behavior data is dependent, but then on the other hand, by algorithmic operations, the same data is now independent.

In order to determine the effects of results for using different kinds of statistical tests in treating information measures, it was decided to assume that the data was not independent. The test of this assumption was to use the data of principle two (see page 6) for a step-wise linear regression analysis (BMD-02R). This program computes a sequence of multiple linear regression equations in a stepwise manner. At each step one variable is added to the regression equation. The variable added is the one which makes the greatest reduction in the error sum of squares. Equivalently it is the variable which has the highest partial correlation with the dependent variable partialled on the variables which have already been added.

The first loader was found to be the H(x) measure. However, as other variables were added to the regression equation, the F value needed to remove H(x) from the equation decreased. In fact, by the loading of the 12th (of 30 information measures) measure, H(x) was removed from the equation. It was thus concluded that the algorithmic dependability strengths of the information measures were not as strong as had been initially anticipated.

A second study was made of the serial correlation of variables in the experimental data of PIMM. The DAM-03 last-loader multiple regression analysis was used in this study. Several sets of experimental data were studied. The Durbin-Watson statistic (23) was used for measurements of serial correlation. It was found that the usual variable loads were non-serial. An interesting observation was that non-serial correlations ensued when the historical and property differences of behavior data increased. An example is the behavior data collected on the processing of two different kinds of tasks by the same group of humans (not reported in this symposium). The two kinds of task involved information processing strategies in recall and problem solving tasks. It was found that variables of task one had greater degrees of serial correlation in the significant relationships with the cognition for task two, than were the second task learning variables which were related to the cognition of task two. This paradox was made more complicated by another finding. Multiple regression total load forecasts for the information flow of the behavior processing of both tasks were compared. The dependent variables, in both analyses, were the cognition scores for task two. The same H-measures were used for regression loadings for each of the two tasks. Three major loadings were done with H-measures which are claimed to represent levels of short and long term memory stores. The forecasts of total loads for the variance of cognition scores decreased as the loadings simulated a "passage to the long term memory store". An example of load forecasts for the three analyses of each of the tasks were: .71, .44, and .29 for task one, and .47, .38, .08 for task two. As can be seen, the short term memory flow forecast was greater than long term memory flow forecasts. The degree of serial correlation increased positively for the same direction, or as the forecast decreased in value. The paradox is then one of differences between groups of H-measures operating different memory process designates their Markovicity of independence, time trends for different task information flow and the independence of variables. PIMM is continuing a study of this interesting situation.

The final problem in the statistical testing of the memory model is one of great magnitude. The basic theorem developed by Shannon (1), in Information Theory involves the summation of a series of negative logarithms. The algorithmic outcome is an entropy value for each behavior of those behaviors involved in the experience. The algorithms obtained from this theorem become more dependent, as shown in Figure Three, and lead to a question of independence of relevant variables. There has been some attention to this problem. Clearly variance kinds of tests between information measures would be tenuous. An interesting sidelight has been the use of information measures to test the independence and self-importance of data. Char-Tung Lee (26) has done this successfully by using conditional measures such as $H_y(X)$. His position was that X and Y variables are independent of $H_x(Y) = H(X)$ or the previously mentioned proof arrived at by PIMM. Taking this into account it seems more logical to use regression types of analyses for treating memory model processes and components.

Problem Solving Behaviors and Perceptive Modalities

Barbara K. Felen

As an attempt to explore the potential of an information theoretic model in the analysis of overt problem-solving responses, students in grades one through twelve were given a dry cell battery, a single throw switch, two miniature light receptacles with bulbs, and five wires with alligator clips at both ends. They were instructed to put the materials together so that both bulbs would light up and so that when both bulbs were lit they could unscrew one bulb and still have the other one remain lit. The instance of having both bulbs lit was defined as a test situation. The test situation was considered negative in the case of a series circuit and positive in the case of a parallel circuit. The various wire connections made by each student were recorded on eight by eight matrices, rows and columns of the matrices being representative of the various problem step components. Information measures were calculated directly from these matrices. The groups of solvers were classified into two categories, successful and unsuccessful. Each category was then further subdivided so as to be representative of grades one and two, three through five, six through nine, and ten through twelve. Mean information measures for each of the eight resultant groups (success and failure) were determined and analyzed in an attempt to distinguish patterns of information flow. Simple correlations and multiple regression analyses (DAM-03) were applied as tests of significant relationships. Herein, a group's number of test situations processed and number of connections made were examined to determine their credibility in predicting mean information flow variance.

The definition of LTM in M^1 as new "chunked" information in the short term memory store and LTM in steady state as information retrieved from the long term memory store along with an examination of these figures in Table Six contributed greatly to our understanding of factors affecting problem outcome. Since, in all cases, LTM steady state values were greater than LTM M^1 values, it could be inferred that all groups manipulating the parallel circuit problem processed their greater amounts of information in the long term memory store. Successful problem solutions of children in concrete and formal operational levels (as established by grade level standards) were characterized by amounts of long term memory retrieval that were greater than those displayed in unsuccessful solutions. Thus, success in grades three through twelve was due to an increased ability to retrieve previously stored memory experiences. In turn, failure ensued as the efficiency of long term memory retrieval decreased.

Examination of LTM percentage values in M^1 also revealed that information measures could be indicative of mental maturation levels. As students' reasoning powers developed through concrete and formal operational levels (as indicated by an advancement from grades one through twelve), they appeared to process the parallel circuit problem by employing progressively greater usage of their short term memory store, this usage always being more pronounced in the case of unsuccessful student groups who were compared to their corresponding successful counterparts. Thus, mental maturation as related to problem solving was a function of decreased retrieval of material "learned" through experience.

TABLE FIVE

$H_X(Y)$ R.E. for Circuit Connections by Grade Groups

PROBLEM OUTCOME: for $H_X(Y)$ RE		Grade Groups 1-2	3-5	6-9	10-12
Successful:	Mean	.5041	.6048	.5329	.5507
	S.D.	.1526	.0993	.1479	.1521
Unsuccessful:	Mean	.5478	.5240	.5270	.5243
	S.D.	.1331	.1202	.1194	.1208

At the concrete and formal operational levels problem outcome was also found to be related to the various noise levels existing in steady state conditions. Successful students in all cases had larger amounts of total useful information accompanied by correspondingly lower total noise levels. Noise levels were also lower in both first and second alligator clip connections (NOISE IN X AND NOISE IN Y) processed by successful groups. Since useful (REAL) steady state information was identical to LTM at steady state, the previous claim that successful students retrieved more information from their long term memory store was again supported.

Simple correlation analyses applied to various information measures showed that the number of connections processed by a student served as a good predictor of his LTM value in M^1. When a student was successful an average of 71% of his variance in M^1 could be predicted, this prediction of LTM variance remaining fairly constant throughout the successful grade groupings. However, in the case of unsuccessful students this accuracy of prediction was reduced as grade level increased (80% in grades one and two to 55% in grades ten through twelve). In steady state conditions connections could forecast the variance of long term memory retrieval in grades three through nine for successful groups and in grades three through five for unsuccessful groups. Herein, negative correlations existed with LTM measures whereas in M^1 these correlations were positive. This implied that as number of connections increased information in the short term memory store increased, while information retrieval from the long term memory store decreased. The observed correlation pattern supported previously discussed aspects of the memory model (i.e. as students advanced through grade levels they drew more information from the short term memory and in turn decreased information drawm from the long term memory store). In the case of multiple correlation analyses, connections as last loaders continued to significantly predict variance existing in the short term memory for two of the three successful grade groups and for three of the four unsuccessful grade groups. However, in steady state conditions the variance of LTM could be forecast for only the unsuccessful. A study of forecast levels showed that the variance of all steady state H measures could be predicted, this prediction being possible only in the case of the unsuccessful. Here, the entity of "connecting" as a task in the real world was sufficient in itself to predict information values. In the case of successful students, students who not only "manipulated" but also drew from experience, the act of connecting alone could not predict events with such accuracy.

A consideration of correlations between information values and tests afforded a further insight into instance factors affecting problem outcome. In the case of unsuccessful students the variance of uncertainty of the second alligator clip connection, given knowledge of the first alligator clip connection (R.E. of H_x (Y)), could be predicted in all unsuccessful groups. The correlation here was negative, implying that as number of tests increased, uncertainty decreased (This could also be viewed as an increase in the level of redundancy). Reference to mean R.E. of H_x(Y) values (Table Five), showed that for all concrete and formal operational groups uncertainty for succeeding was always at a higher level. On the surface this may appear as a contradictory statement for success seems to imply that certainty is operating on the part of the problem solver. However, the act of testing for the unsuccessful was always a negative instance. According to Bruner (27) "a long series of encounters with negative instances often requires the person to adopt modes of solution that are predominantly devoted to reduction on memory strain." In the language of PIMM the unsuccessful chose to reduce uncertainty. Successful students followed negative instance encounters with exploratory responses and in turn raised uncertainty. Thus, willingness to "take a chance" or ability to inhibit an incorrect response tended to influence problem outcome.

TABLE SIX

Short and Long Term LTM for Circuit Connections, by Grade Groups

PROBLEM OUTCOME:		Grade Groups 1-2	3-5	6-9	10-12
1) LTM-Mi					
Successful:	Mean	0.0775	0.1490	0.2478	0.2161
	S.D.	0.0060	0.0730	0.1767	0.1143
Unsuccessful:	Mean	0.1272	0.2266	0.2993	0.3457
	S.D.	0.1149	0.1712	0.1754	0.1838
2) LTM-SS					
Successful:	Mean	.2877	0.7552	0.7584	0.9277
	S.D.	.0106	0.4512	0.4748	0.5085
Unsuccessful:	Mean	0.7466	0.5632	0.5119	0.5405
	S.D.	0.2919	0.3450	0.3362	0.3513

According to Young (28) learning is a process involving inhibition of incorrect response and intelligence is a capacity for inhibition (Note his definition of intelligence bears little direct relationship to I.Q.). In this experiment, learning to solve the parallel circuit problem could be viewed as learning to inhibit incorrect response. Since success was found to be in no way correlated with intelligence scores, the definitions of Young are supported. As Young verbally defined learning, this study has attempted to define the problem solving aspect of learning via information theoretic measures and as problem solving is so vital a part of the whole of learning theory, a mathematical whole (in light of this and other studies outlined here) may be anticipated by educators.

The Cognitive Structure and Information Flow Characteristics of Children Who Received Instruction in Sorting Practices

David L. Dunlop

This study was done to explore the effects of advance organizers on the information flow of 15 year old children. The task situation which was used for instruction was one of how to classify real world groups of objects. Eighty-four children were given a task of classifying a display of 14 pictures of different kinds of animals. The experimental conditions were described in principle nine (page 27). The set formations were quantified to obtain 11 information measure values (hereafter called task one). Later, the children were given a 305 word passage on how to classify elements (task two). After reading the passage, they did a recall task by writing a statement of what they had read. The recall statements were scored and dichotomized into a "low" learning group and a "high" learning group.

The third phase of the experiment was to test the effects of the instruction in classifying. A new set of 14 pictures of animals was displayed to the children (task three). The children sorted the figures into sets by using the identity numbers of the animals. As was done in the preceding classifying practice, the set formations were treated for 11 measures.

The information flow measures, as defined by the 11 algorithms in task one and task three, were used as independent variables in last loading multiple regression analyses (DAM-03). The dependent variables were the practice learning characteristics and the recall scores for tasks one and three.

The "high" learning groups behavior traits are shown in Table Seven. This table lists the results of the regression analyses for tasks one and three, or before and after an instructional experience. Prior to the instruction experience (task two, above), the NOISE:X measure was of only minor importance in forecasting set formations (practice labels in Table 7) and cognition. The information measures CODE, $H_X(Y)$, and REAL-SS were of even less importance in forecasting the cognition and practice characteristics. However, it can be seen that after the learning experience (task three), CODE became significantly more important in forecasting cognition and practice characteristics. The measures NOISE:X, $H_X(Y)$, and REAL-SS were also found to be more important forecasters after learning.

The levels of forecasts of the same characteristics are shown for the "low" learning group of children in Table Eight. By comparing the "low" and "high" learning group characteristics forecasters, we can find meaningful differences. There was a conspicuous absence of the CODE measure as a significant predictor before (task one) and after (task three) the learning (task two) had taken place. The NOISE:X and $H_X(Y)$ information measures did not generally increase in forecast levels after the learning experience had been given. The REAL-SS measure followed a pattern similar to that for the "high" learning group. However, its importance as a forecaster was reduced.

An analysis of the components of cognition for the "low" and "high" learning groups was done by comparing them as a set, i.e., recall shape, recall name, recall number. The "low" learning group had a shift from five to nine significant cognition forecasters, after training. The "high" learning group moved from six forecasters before training, to eleven cognition forecasters after training. We interpreted this to mean that both groups had experienced instruction which resulted in information flow shifts for the task cognition.

The shifts in forecasters for the sorting task processing showed that the effects of instruction differed for the two groups which had obtained different levels of learning from instruction. The table entries, beginning with "practice", were used to study this finding (see row labels of practice shape through practice "other"). The "low" learning group had 14 significant forecasters prior to instruction and a decrease to 10 significant forecasters after instruction. Furthermore, five of these 10 significant forecasters were for the practice "other" trait, where it had none for this trait, prior to instruction. The "high" learning group had 11 significant practice forecasters before instruction. There was an increase to 14 significant forecasts after training. It seems that the two groups differed as to the effects of the instruction on their classifying of objects.

The changes of forecastability by information flow in practicing set formations in a sorting task after being instructed to classify were again examined for learning level differences. Compare the practice characteristics area of Table 7 and Table 8 . Notice that none of the 11 H-values significantly predicted the variance of recall shape for the "low" learning group. The same learning group had four flow forecasters of the variance of practice shape prior to instruction but only one after instruction. On the other hand, the "high" learning group had four significant forecasts of recall shape after instruction, as compared to only one prior to instruction. However, the change in practice forecasting was very pronounced after instruction. The "high" learning group had an increase of from three to six significant forecasters after training. The post-instruction changes revealed a marked pattern in the flow of information for the cognitive processing of the attribute of animal shape. The interesting point was that the "high" learning group showed a significant gain in recalling shapes of animals from task one to task three. Notice that the H-values which were significant forecasters prior to instruction failed to do so after instruction.

The post-instruction recall and practice forecasts for the "high" learners were quite redundant in the roles of information theoretic measures. The flow pattern effects of instruction were: a) practice learning input (H(X)), CODE in the short term store, the correction of information errors ($H_y(X)$), channel flow of useful (REAL) and spurious information (input as NOISE:X), and short term memory output (H (Y)); b) cognition flow redundancy for CODE $H_y(X)$, and REAL; c) the cognition operator of sharing (H (X,Y)) information between consecutive elements of information. This pattern is uniquely apparent when compared to the pre-instruction information flow pattern. This was one of conditionality for flow ($H_x(Y)$), dependence between elements (M^{16}), the short term memory organization of information (LTM), and cognition channel spuriousness (NOISE:X).

The "low" learning group had changes in information flow forecasts which could be explained in patterns as was just done for the processing of shape information by the "high" learning group. It can be seen in Table Eight that the instruction effects were on changes in the processing of the name of the animals displayed and their identity numbers. The instruction effect was a shift to cognition regarding the names of the animals. The processing of identity numbers was one of short term memory storage in the experience and a long term memory storage for subsequent cognitions. The CODE memory component played a major role in the cognitive structure of the identity number elements.

Several conclusions can be drawn from the findings of this experiment. It is clear that the two groups were different in their processing of learning experiences. The "high" learning group, which apparently utilized advanced organizers, shifted to the target of the shape of animals in practice sorting and information receiving and storage. This was a change from when the major information processing was of the geographic location (pattern) of the animals on the pictorial display. The "low" learning group developed processing tendencies for the names and identity numbers of the animals after receiving instruction on classifying.

The information flow forecastability of learning input and cognition in the processing of a task is thusly altered by the use of advance organizers. More importantly, the forecast shifts indicate that cognition or recall is an effect of instruction, particularly for efficient learners. The major memory flow issue is how the received information was coded and then stored in the short and long term memories.

These conclusions may seem to be quite intuitive, particularly if you are a proponent of the Ausubel School of Learning. The PIMM group is not of an active school membership, but it conducted the experiment as an exploration of the veracity of the theory. It seems that the concept of advance organizers was a discriminating factor in the experiment. High learners did differ from low learners in learning facilitation and information processing. By using a PIMM approach, it was possible to confirm these aspects of the school of learning. The question of "ordinate" kinds of cognitive subsumptions is still being analyzed. This question is being explored by the PIMM feasibility for the mapping of memory processes and components with information theoretic measures. The target is to examine the roles of the short term and long term memory measures to test the Ausubelian concept of high and low "subsumming" discriminabilities. We suggest that, in the reported experiment, discriminability was actually the quality of steady state measures in the memory model of PIMM.

TABLE SEVEN

Significant Forecasts of Variances of Practice Learning and Recall Characteristics, "High" Learning Group of Children

Characteristic	H(X)	$H_x(Y)$	CODE	H(Y)	$H_y(X)$	REAL-M[1]	LTM	REAL-SS	H(X,Y)	M^{16}	NOISE: X
	Information Measure										
Total Recall			.16*					.18*	.11*		.11 .22*
Recall Shape			.19*		.12*	.15*			.08*		.10
Recall Name		.09*	.09 .17*			.09		.13*			
Recall No.		.13	.15*				.08	.18*	.11*		.14 .22*
Practice Shape	.12*	.18	.12*	.22*	.08*	.08*	.18			.21	.13*
Practice Name									.14*	.08	
Practice No.										.07	.09
Practice Pattern		.08	.08	.18	.08		.10*	.09			.09*
Practice Attributes											
Practice "other"			.30*	.16*	.11*			.14*	.27*		
Total Sets (Pract.)		.08 .11*	.09		.07	.08 .14*	.16*	.18*			.10*
Messages (Pract.)			.10		.08	.11	.21*	.19 .21*	.22 .21*	.32	.12 .37*

*Indicates forecasters of task three; otherwise forecasters for task one are listed as non-scripted numbers.

TABLE EIGHT

Significant Forecasts of Variances of Practice Learning and Recall Characteristics, "Low" Learning Group of Children

Characteristic	Information Measures										
	H(X)	$H_x(Y)$	CODE	H(Y)	$H_y(X)$	REAL-M^1	LTM	REAL-SS	H(X,Y)	M^{16}	NOISE:X
Total Recall		.06		.06	.06*	.05*		.07 .07*	.05		
Recall Shape											
Recall Name				.06 .11*	.11*	.22*		.04 .13*	.11*	.06*	.08*
Recall No.		.10	.09*					.05 .06*	.08		
Practice Shape	.04				.12	.07					.48 .06*
Practice Name				.09		.06				.08	.04
Practice No.			.05*		.28	.21	.05*		.10	.51 .05*	.04
Practice Pattern								.12*		.10	
Practice Attributes											
Practice "other"	.08*			.15*		.06*		.06*	.06*		
Total Sets (Pract.)				.05						.21 .04*	.25
Messages (Pract.)		.07	.08*	.07	.14*		.07 .08*	.06*	.12 .04*	.17 .52*	.19*

*Indicates forecasters of task three; otherwise forecasters for task one listed as non-scripted numbers.

Structuredness and Learning Behaviors

Frank Fazio

In this study an attempt was made to relate learning with changes in structuredness as implied by the uncertainty measures of the information theory used in this model. In the Encyclopaedia of Cybernetics (29), a brief survey was made of several stochastic learning models which use a stochastic matrix. All of these models agreed that the entropy (uncertainty) of the system of possible reactions decreases during the learning process. Hintikka and Suppes (30) presented various models relating learning and the structure of information. They derived a learning curve for a transition matrix. Watanbe (31) proposed the inverse H-theorem described as the "Entropic Theorem of Learning". He showed that the entropy (uncertainty) increases at the beginning of the learning process then gradually decreases when real learning begins. Shannon's (1) interpretation is similar to Watanabe's inverse theorem. Shannon's fundamental theorem relates that the amount of information (H) for a string of successive symbols is approximately the logarithm of the reciprocal probability of a typical long sequence divided by the number of symbols in that sequence. Attneave (3) likewise concurs that an uncertainty decrease is an indication of a measure of patterning or structure.

The assumptions of this study are the same as those stated in other parts of this symposium. They are that man's cognitive processes operate as an approximate ergodic source using a stochastic process and Markovian chain reasoning. Man's behavior is considered Markovian since the probability of occurrence of a specific behavioral event will depend upon the previous behavior. This specific study involved an investigation of the structuredness of the overt concrete problem-solving behavior of 243 college students working on three related electric circuit tasks. Problem solving in the real world involves the recognition of a goal and the devising of strategies for processing the solution. The behavioral sequences of college students solving electric circuit problems were coded as to the location of the terminal where the connecting wires were placed. The two-bulb parallel circuit task had eight possible connecting terminals while the three-bulb parallel task and the three-way switch task had ten possible connecting posts.

The order and sequence of the coded behavior (A,D, B, A, C) was placed in an interaction or transitional matrix. This matrix shows the distribution of the links of the chain of behavior. This transitional matrix also displays the conditional probabilities which can be calculated for each (i,j) cell entry. The patterns or the structure implied in these matrices (respective dimensions of 64 and 100 cells) can be seen as a distinct function of the number of entries and the percentage of cell occupancy. A random matrix would be more likely to have the number of entries uniformly or evenly distributed while a matrix with some structure or pattern would have certain configurations of empty cells.

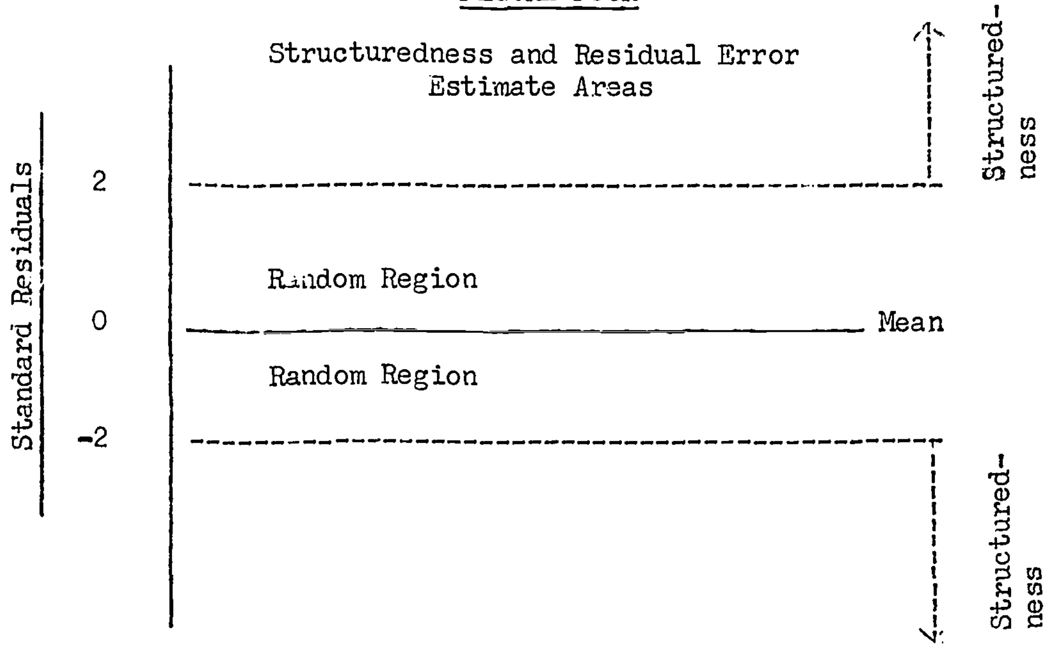
The transitional matrix can be indicative of the structure or the non-randomness of a subject's problem solving behavior. As a subject increases the number of problem-solving pathways, it can be expected that: (1) the distribution of the matrix cell occupancy increases, (2) the conditional information ($H_x(Y)$) increases because of the interaction of the pathways for a set number of solution steps in solving the circuit tasks, (3) the amount of noise in the input channel will also increase.

In order to establish criteria for a random matrix, a computer program was written to simulate the behavior of the college students solving the electric circuit tasks in a random fashion. The computer output was a randomly generated transitional matrix. From many sets of random matrices, regression equations were determined to predict the expected random information measures (Y): from the predictor variables (X_1) for the number of entries, and (X_2) for the percentage cells occupied. The general random regression equation was expressed as:

$$Y = X_1 + X_2 + c, \text{ and where c is the intercept}$$

Regression equations were determined for each of the following information measures: $H_x(Y)$ R. E., Code, Percent Code, Percent Real, LTM, NOISE:X; for each of the three tasks. As a result of being able to predict the expected random values, it was possible to compare the real world cognitive behaviors to that of the expected random behavior. A scale of structuredness was determined in order to make these comparisons. The random region was the area between ± 2 standard-error-of-estimate values from the expected mean regression line. Structuredness was defined as increasingly moving away from the random region. This concept is shown in Figure Four.

FIGURE FOUR



The research design permitted comparisons and contrasts to be made of subjects involved in one, two, or three electric circuit tasks. In addition, individual training sessions were provided to determine if the model components could be used to detect and quantitatively measure changes in behavior structure as a result of training. It was hypothesized that learning is proportional to structuredness. The proposition was that the more structured the output, the greater would be the degree of learning.

The findings of the study consistently showed that conditional Information Relative Entropy ($H_x(Y)$ R.E.) and the NOISE:X components showed a decrease in value to be indicative of structuredness. On the other hand, as the CODE, % CODE, % REAL and LTM information values increased, there was a tendency toward more structuredness. Sixty-seven percent of the comparisons of groups succeeding with groups which failed to solve the electric circuit problem were found to be significantly different with respect to their structuredness.

Training caused a more structural change in sixty percent of all the information values for the three-way switch task, while the same training produced a more structured change in eighty percent of all the information values for the three-bulb parallel circuit task.

Graphical profiles were constructed as shown on Figures Five and Six. These graphical representations provide the researcher with a quick survey of the changes in the structuredness that have occurred in the information measures as a function of the electric circuit task and the training provided.

Both figures indicate that almost all of the values for the first parallel circuit task were operating in the random region. It may be inferred that this initial task was being processed with a great deal of non-structuredness or random behavior. With task experience and training, however, the information values can be seen to generally move toward more structuredness. This was indicative of learning taking place as a result of task experience and training. This was partially validated by comparing the success group with the failure group. The success groups category 7 and 13 had more structured values than the failure groups category 8 and category 14. All four values of category 7 for the post-training task were more structured than the corresponding values of category 8. Three values for category 13 were more structured than the three information values of category 14. The only interesting exception was the LTM value; it seems to show a steady increase across all tasks.

The findings in this specific study lend strong support to other studies described in this symposium. The model components that were tested with respect to the structuredness construct have proven to be quite valuable in other studies. This study has shown that the criteria values for a problem-solving task using the information measures of Conditional Information Relative Entropy and the Noise in the Input $(H_y(X)/H_x)$ were replicated. The electric circuit tasks used in this study were being processed by the subjects using a problem-solving mode of information processing.

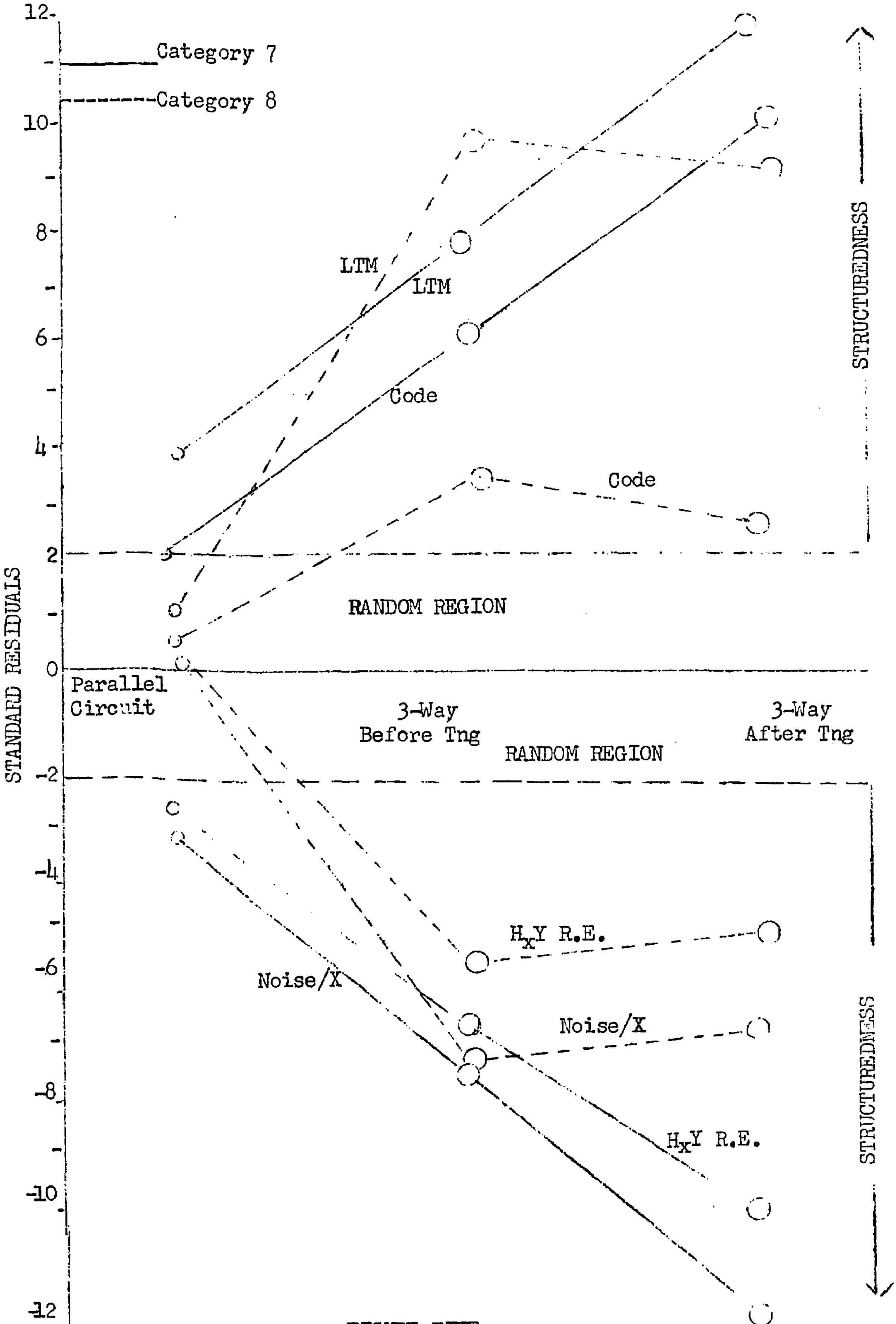


FIGURE FIVE

Categories 7 and 8 Information Measures As A Function of Electric Circuit Task

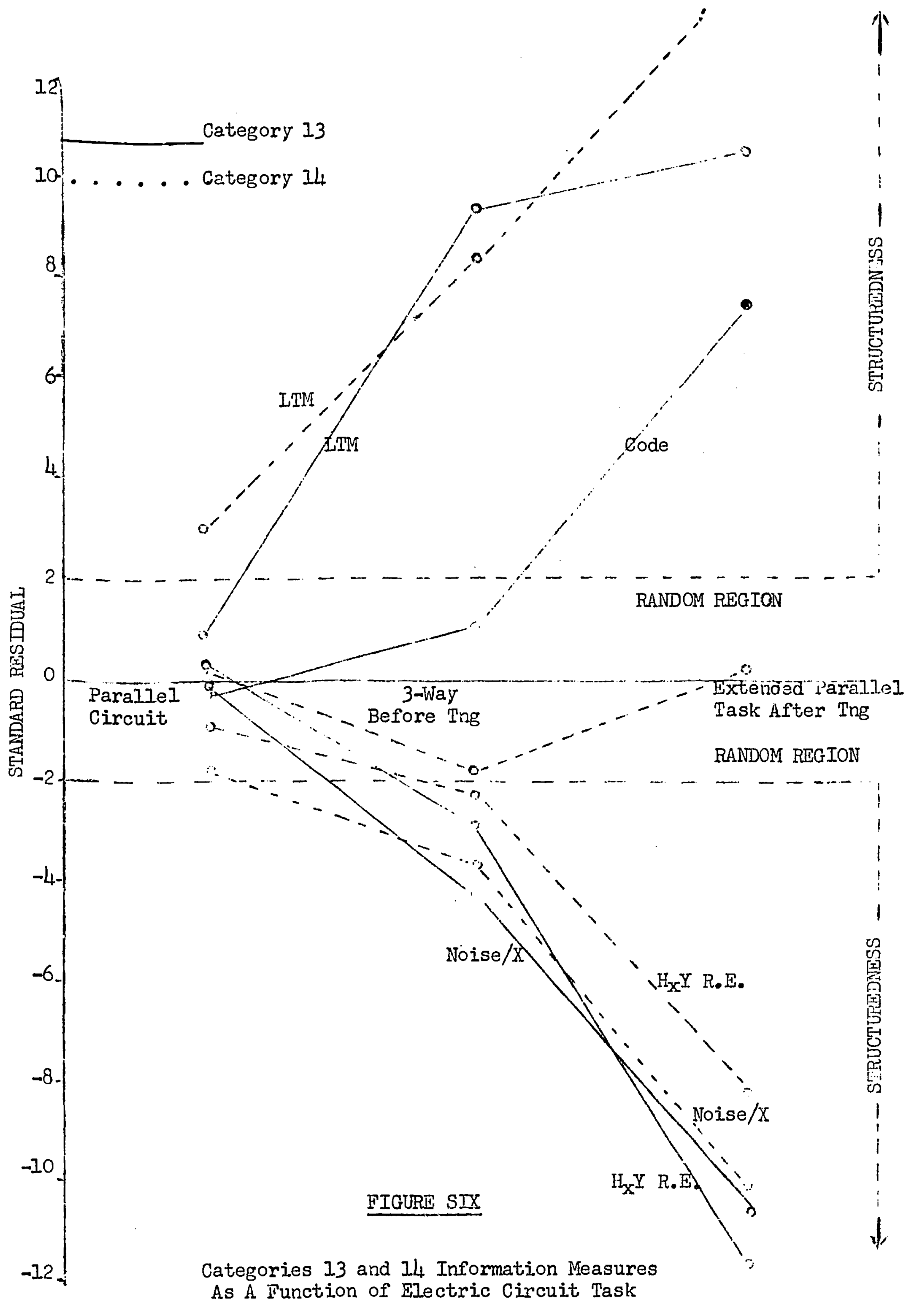


FIGURE SIX

Categories 13 and 14 Information Measures
As A Function of Electric Circuit Task

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